

Final Report

**NASA CR71026**

for

A Detailed Failure Analysis of the Ball Bearings

From a Model 1631 Tape Recorder

December 1, 1964 to November 1, 1965

Contract No.: NAS 5-9525

Prepared By

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for

Goddard Space Flight Center

Greenbelt, Maryland

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## ABSTRACT

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In order to extend the life of a Nimbus tape recorder a study was conducted on the cause of recorder bearing failures. Various studies were made to evaluate the nature of the bearing failures and establish the required corrective action. Positive indications of lubricant oxidation were found and recommendations are made to reduce the oxidation difficulty. Work remains to be done to test the recommendations as well as follow through testing of points incompletely covered in the work.

*Author*

## INTRODUCTION

In the belief that a considerable increase in ball bearing life can be accomplished, a detailed study of the reasons for bearing failure in a specific recorder was undertaken. The bearings appear to be a prime cause of recorder failure and previous bearing failure analyses have not been able to explain the lack of operating time. These previous failure analyses have suggested that the failure may be related to chemical problems affecting the lubricant and, thereby, causing bearing failure due to the formation of resinous appearing compounds (see Appendix). The contract work, however, was kept as broad as possible in an attempt to uncover the true cause of the problem whether it be mechanical, electrical, or chemical.

The conduct of the investigation followed three principal avenues of approach. The first involved mechanical aspects such as bearing loads, alignments, fit in housings, abuse and general misapplication. Although considerable effort was made to find a situation that might be considered to mechanically overtax the bearing, no such indication could be found.

The second approach was to chemically analyze the lubricant and lubricant climate, recorder encapsulating gas, the bearing metal surface chemistry, the loose wear debris and contamination in the enclosure of the recorder, in addition to the lubricant or lubricant residue. The matter remaining after washing from the two bearings that actually reached failure condition and stopped the recorder were also analyzed. The results of this type of work are not as clear as the mechanical inspection in that possible adverse conditions are recognized but a positive cause and effect relationship cannot be documented.

The third approach was to involve a manufacturer of a lubricant of similar nature to that involved with the recorder as a consultant. The operating conditions of the recorder and all data associated with both the mechanical and chemical analysis work was given to the consultant as well as information regarding the chemical nature, history and any idiosyncrasies. The type of information thus obtained from the oil manufacturer can by itself form a recommendation for future specification of lubricant and gaseous environment.

## MECHANICAL BEARING EVALUATION

The study of the bearings using operating tests and visual examinations

actually began prior to the contract when a duplex pair of SR166P bearings from the jack shaft and a duplex pair of SR2-5P bearings from the pressure roller were submitted to New Hampshire Ball Bearings, Inc. for analysis (see Appendix). These bearings were removed from the subject recorder, NF-1, and identified as causing the failure. The recorder had experienced the following operations: 26 days (624 hours) thermal cycling (0° to 50° C) in vacuum, 25 days (600 hours) assembly and pre-environmental tests, 68 days (1632 hours) spacecraft testing part of the time under temperature cycling, for a total estimated test life before failure of 2856 hours.

The procedure used to examine all the bearings removed from the recorder was the same except the solvent used to wash the jack shaft and pressure roller bearings was not retained for subsequent chemical analysis. These bearings were disassembled from the recorder and their respective mountings by Goddard Space Flight Center personnel and thus, the recorder encapsulation gas was lost. The bearings involved in the contract were disassembled from the recorder using care to observe the fit and condition of the bearing in the assembly. The disassembly work at New Hampshire Ball Bearings, Inc. was done in a controlled temperature dust shield in order to preserve the condition of the part for further chemical identification work. The bearings were run on a Mil-Std-206 running torque tester to assess their overall operating condition. The tester involved in the Mil-Std-206 test is an Asch instrument which rotates the bearing at one-half rpm in a vertical axis position under a light thrust load. The inner race of the bearing is restrained from rotating by a sensitive force measuring system which in turn electrically indicates the magnitude of the force on a strip chart. The test is performed for one revolution of the bearing in each direction, each side up of the bearing. The slow speed of the rotation allows the recorder to indicate minute changes of torque due to dirt, as well as drifting of the general torque level which indicates geometrical inconsistencies.

The lubricant and contamination was extracted by solvent dilution after torque testing. The extraction process consists of soaking an individual bearing in a small clean test tube half full of trichloroethylene overnight. The soak is followed by heating to levels below the boiling point and shaking. The bearings are then removed from the test tube by the use of a magnet. This procedure is entirely different from normal "washing" operations where the bearings are sprayed with trichloroethylene that is continually exhausted with a venting system. In normal washing the bearing is held in the solvent spray so as to allow it to spin, which is an aid to flushing. The cycle is concluded by a stream of warm air to dry the bearing.

In a few cases in the recorder, it appeared advisable to disassemble the

bearing to insure maximum extraction of residue considering the extract would be the prime subject of the chemical investigation. In these cases of bearing disassembly for extraction, the bearings were then reassembled and rerun on the Mil-Std-206 torque tester along with the bearings not disassembled. The disassembly-reassembly did cause some bearing damage that appears generally as geometry defects. The nature of the disassembly in the case of the crown retainer type bearings consists of pushing on the retainer in an axial direction until the retainer ears unsnap over the balls. The process when done properly does not involve any gross damage but often the retainer ears leave drag marks on the balls. The ears are like fingers separating the balls and supported by a ring on one side. The retainer is designed to be pushed in over the equally spaced balls and snap into place. The design intends the removal to be a harder push than occurs during assembly. This fact, plus the fact that normal wear tends to sharpen the square edges of the retainer ears, accounts for the slight damage to the bearing. If the balls are slightly worn and roughened, the drag marks will also be visually more pronounced. The type of marking caused by disassembly is distinctive and is discounted from the assessment of operating damage.

The purpose of the before and after wash or solvent extraction torque testing was to evaluate the quantity and effect of removing any contamination from the bearing and this purpose was largely accomplished.

Visual observations of the bearings were made in every condition from unit assembly to totally disassembling for the purpose of describing the condition of lubricant, contamination, components and associated mating parts of the units. These examinations were performed under magnification of 20 times with specific points checked under 80 times or higher magnification.

The results of these investigations show no evidence of mechanical abuse in design or workmanship and none of the bearings have worn or deteriorated to a point that should materially affect the operation of the recorder in an adverse manner. There are evidences of contamination which vary from such a minor condition as to be insignificant in its present state of development, to gross problems. This situation of contamination included specks of a varnish-like deposit so tenacious that the specks were not removed even by washing. Additionally, the matter that was removed by washing was sufficient to stall the bearing and describes the original failed bearings. Unfortunately, the matter removed from the failed bearings by washing was not retained for chemical analysis as these bearings were examined prior to the contract (see Appendix). The matter removed by washing from the failed bearings was described and photographed and these photographs appear in Figures 1 through 6.

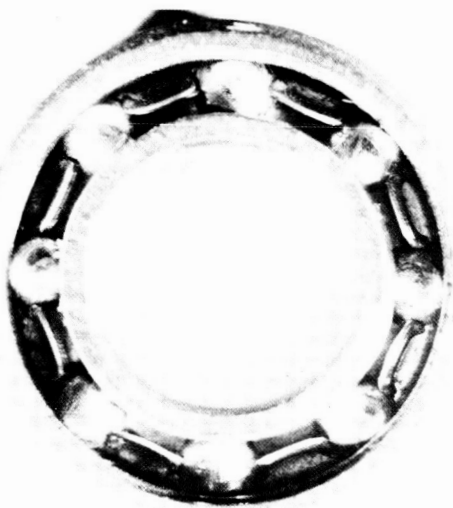


Figure 1  
Jack Shaft Bearing No. 1

Dry curls of lubricant residue  
on the inside of the bearing  
surfaces.

X7

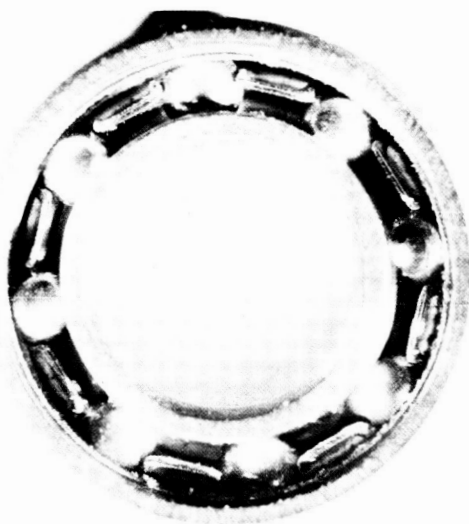


Figure 2  
Jack Shaft Bearing No. 2

Grainy, brown lubricant residue  
with white fibers on the inside  
surfaces.

X7

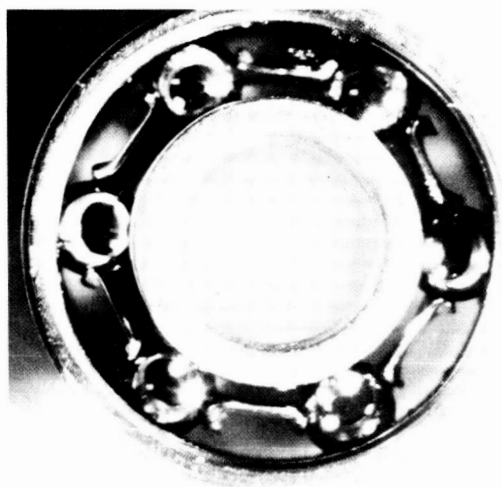


Figure 3  
Pressure Roller Bearing No. 1

Thick, brown, molasses-like  
appearing lubricant residue.

X8.5

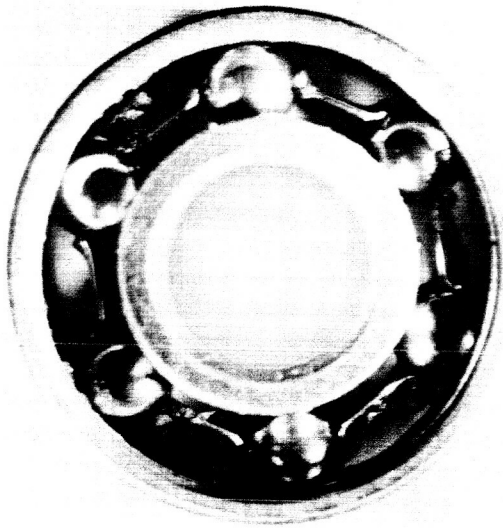


Figure 4  
Pressure Roller Bearing No. 2

Thick, brown, molasses-like  
lubricant residue.

X8.5



Figure 5  
Retainer from Pressure Roller  
Bearing No. 1

After washing, showing gummy  
varnish-like deposits.

X20

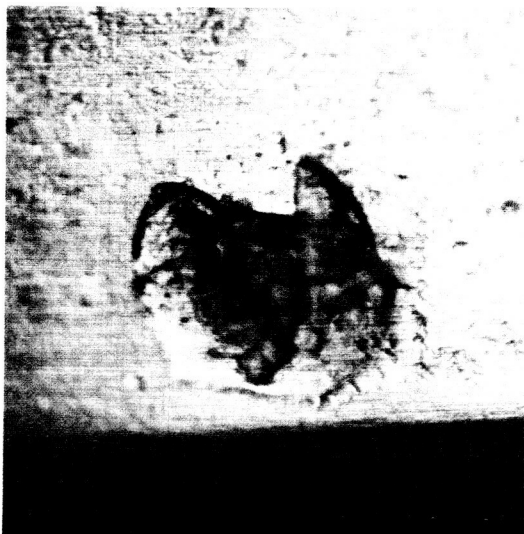


Figure 6

Magnified view of a gummy, brown  
deposit on the inner land of the  
rubber roller Bearing No. 1.

X100

## CHEMICAL RESIDUE IDENTIFICATION

The failure of the jack shaft and pressure roller ball bearings due to a gummy substance displacing the lubricant strongly suggests the need for understanding the chemical change. Since only two bearings actually failed and only four bearings seem to have large quantities of the gummy substance, the sample for identification was limited. As mentioned previously, these four bearings were evaluated prior to the contract and normal New Hampshire Ball Bearings, Inc. procedures were used which washed out the bearings and discarded the solvent. All that remained of the failed bearing deposits at the start of the contract were extremely small, hard specks on two bearings as shown in detail in Figures 5 and 6.

It was reasoned that since the recorder is sealed and all the components are in close proximity with most of the bearings being lubricated with the same oil, and the bearings are of the same manufacture, that it might possibly be that indications of the failure reaction were present in other bearings. If this were true then the residue from all the bearings could be used to try to establish the mechanism that resulted in gummy deposits. If the mechanism could be established then perhaps the specks in the failed bearings would be a large enough sample to verify the cause of failure.

The process of locating any chemical incompatibility involved with the lubricant included the analysis of the recorder gas atmosphere, bearing surfaces, bearing corrosion, base oil, as well as the solvent extractions from the recorder bearings. The evaluation and analysis of the atmosphere gas was actually conducted on two recorders, other than the failed recorder. The disassembly of the failed recorder (NF-1) was done at National Aeronautics and Space Administration to determine the nature of the recorder stoppage and thus, the recorder encapsulating atmosphere was lost. The assumption relating to the atmosphere of non-failure recorders is made that the conditions which resulted in gummed bearings in the NF-1 recorder are also present in other test recorders and will result in failure if given time. The internal atmospheres of recorders NF-8 and NF-14 were sampled and analyzed by gas chromatography on a silicone (Dow 710) column primarily for hydrocarbons, a hexamethylphosphoramide column primarily to check for carbon dioxide, and a molecular sieve column to evaluate the nitrogen-oxygen ratio. The net result of the test found conditions normal considering the nitrogen-helium purge cycles given the recorder. The air consisted of an approximate 90% nitrogen, 10% oxygen in both recorders checked. The nitrogen portion included about 7% helium used for leak detection.

Representative bearings were removed from manufacture at New Hampshire Ball Bearings, Inc. before lubrication and checked for possible

surface chemistry conditions that might be incompatible with the type of lubrication used in the recorder bearings but none were found. Other representative bearings were intentionally corroded and the product of corrosion analyzed for iron-chromium ratio. This was done in an attempt to evaluate the source of some of the contamination in the bearings, especially since iron oxide particles from the magnetic tape were expected. The baseline work did establish that corroded AISI 440-C bearing steel results in products with ten parts iron and one part chromium. Abraded AISI 440-C has a ratio of four parts iron and one part chromium while the recording tape iron oxide has a ratio of 10,000 (minimum) parts iron and one part chromium. Following along this course, solvent extracts from the tape hold-down rolls were analyzed and, in addition to other elements being present, showed a ratio of one part iron per 1000 parts of chromium. Investigation showed that dust from the chromate conversion coating covered the rolls and caused the upset in ratio. It could not be established that this dust chemically affected the lubricant but it is debris in the oil and causes a mechanical increase in running torque of the bearings. The oil segment of the solvent extract from the tape hold-down roll (Unit 641) bearings was not of large enough quantity to obtain clear indications of any chemical change using infra-red spectrographic tests. Since the bearings were very small and the excess oil was centrifuged from the bearings, this difficulty with an adequate sample is reasonable.

In order to obtain as large a sample of oil extract as possible twenty-two bearings from units 601, the playback switch gearbox assembly; 605, the guide roll assembly; 607, the record motor assembly; and 610, the reel assembly, were removed. The bearings were processed as previously described as to testing, inspection, and solvent (trichloroethylene) extraction. When forwarded to the chemical laboratory (New England Laboratories, Ipswich, Massachusetts) the extracts were tested by infra-red and emission spectrography as well as gas chromatography. Fortunately, it was not necessary to combine more than the extract from two bearings to obtain a large enough sample. When bearing extracts were combined, the extracts were always from the same units. The infra-red spectrographic work showed no profound changes in the oil that could not be ascribed to the solvent. These results were compared to control samples of both the oil and solvent. A number of extracts showed some indication of oxidation of the oil on the infra-red traces of which representative samples are shown on the following pages. Only a trace of hydrolyzed diester oil could be found. The infra-red spectrographic work indicates expected conditions with the oil still in fairly good condition. The results of the gas chromatography on these bearings, however, show changes of major magnitude. These changes have not been positively identified but could be oxidation.

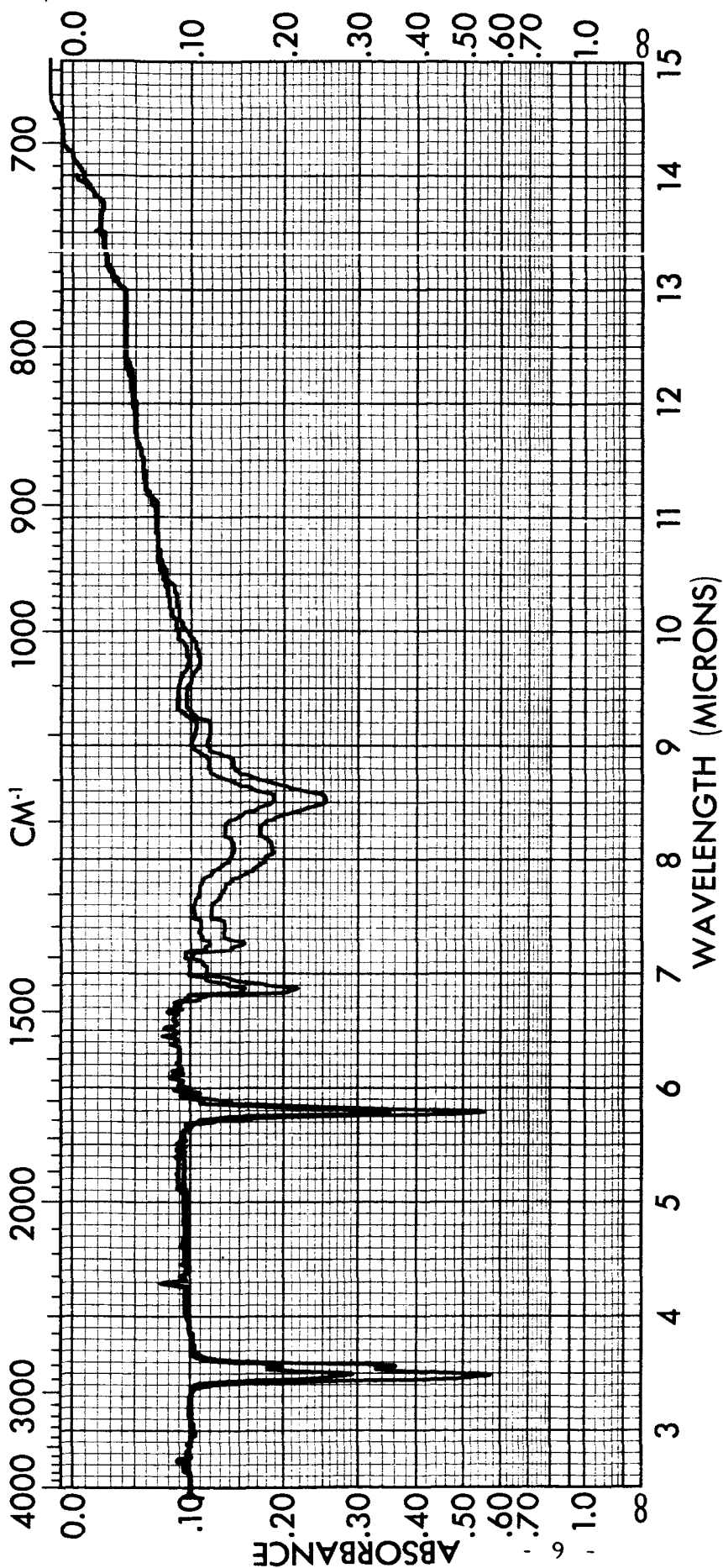
The jack shaft bearings (616 - 1 and 2), Unit 608 and the pressure roller bearings (616 - 3 and 4) Unit 609, which were the bearings which actually

failed, were subjected to solvent extraction of the specks of residue remaining after the original failure analysis. Emission spectrographic results show traces of a number of metals such as chromium, magnesium, iron, nickel, and aluminum to be present in the residue with "moderate" amounts of barium. Since it is believed that the corrosion inhibitor in the particular oil involved is barium sulphonate, the presence of moderate amounts of barium suggests that the residue found in the failed bearing lubricant may be grossly transformed oil. The infra-red spectrographic inspection performed identified the residue as a diester oil and showed clear indications of oxidation of that oil. The largest quantity was found in the 616 - 3 pressure roller bearing and the infra-red spectrographic trace is included in the following illustrations. Gas chromatography work was not possible on the jack shaft and pressure roller bearing extracts.

Figure 7    An infra-red spectrographic trace of a reference sample of L-245X oil meeting Mil-L-6085A specification.

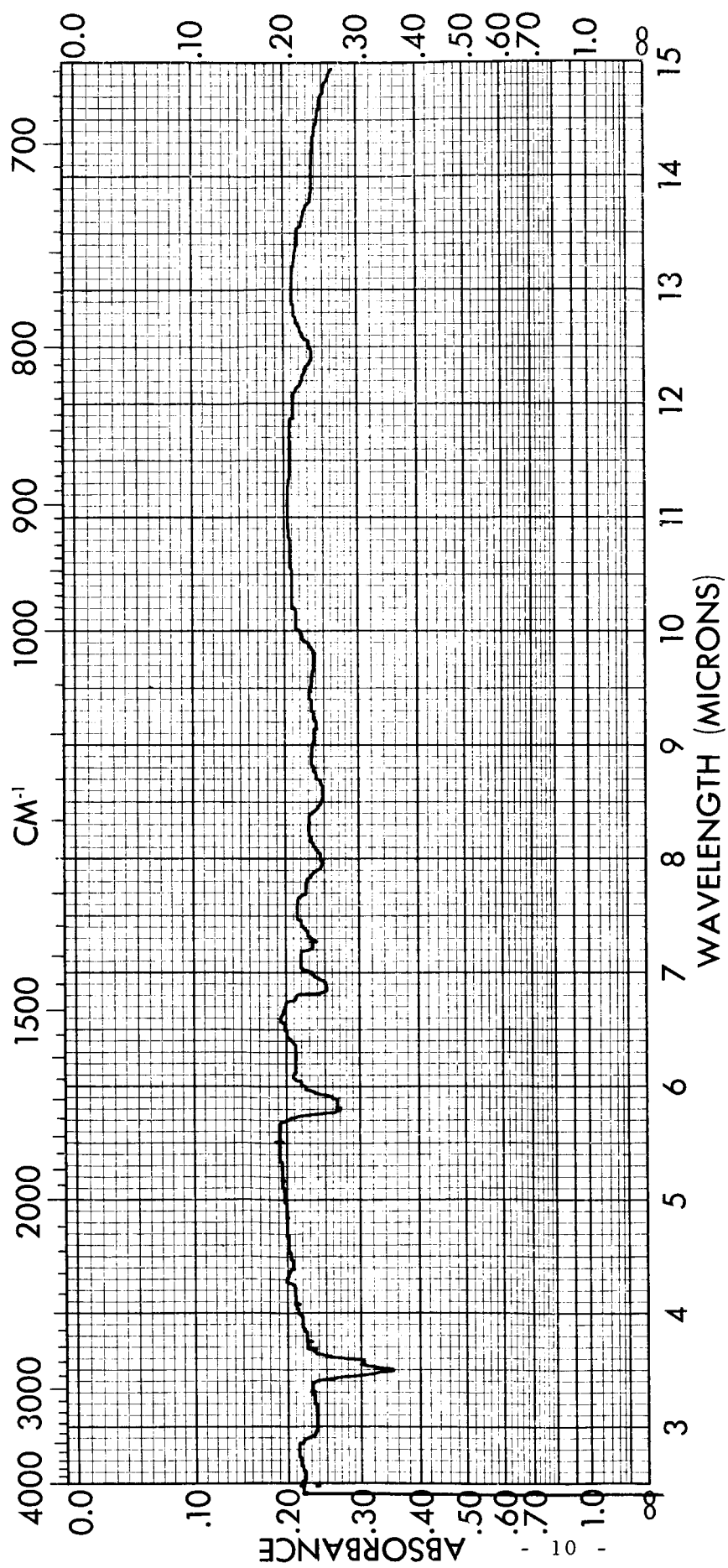
Figure 8    An infra-red spectrographic trace of lubricant from two bearings (601 - 15.11 and 601 - 35.2) from the playback switch gearbox assembly showing a broad band and 5.8 to 5.9 microns indicating oxidation. Neither the bearings or the oil, however, are considered to be failures.

Figure 9    An infra-red spectrographic trace of the residue from a failed bearing showing definite oxidation. The bearing is from the pressure roller assembly (616 - 3 ) Unit 609. This is the infra-red spectrum of an aliphatic ester. There are bands 6.3 and 6.8 that are usually aromatic. The carbonyl peak is doubled indicating two carbonyl materials. The 3.0 region shows an alcohol. Taking the spectrum as a whole, it is consistent with an ester where some oxidation has taken place.



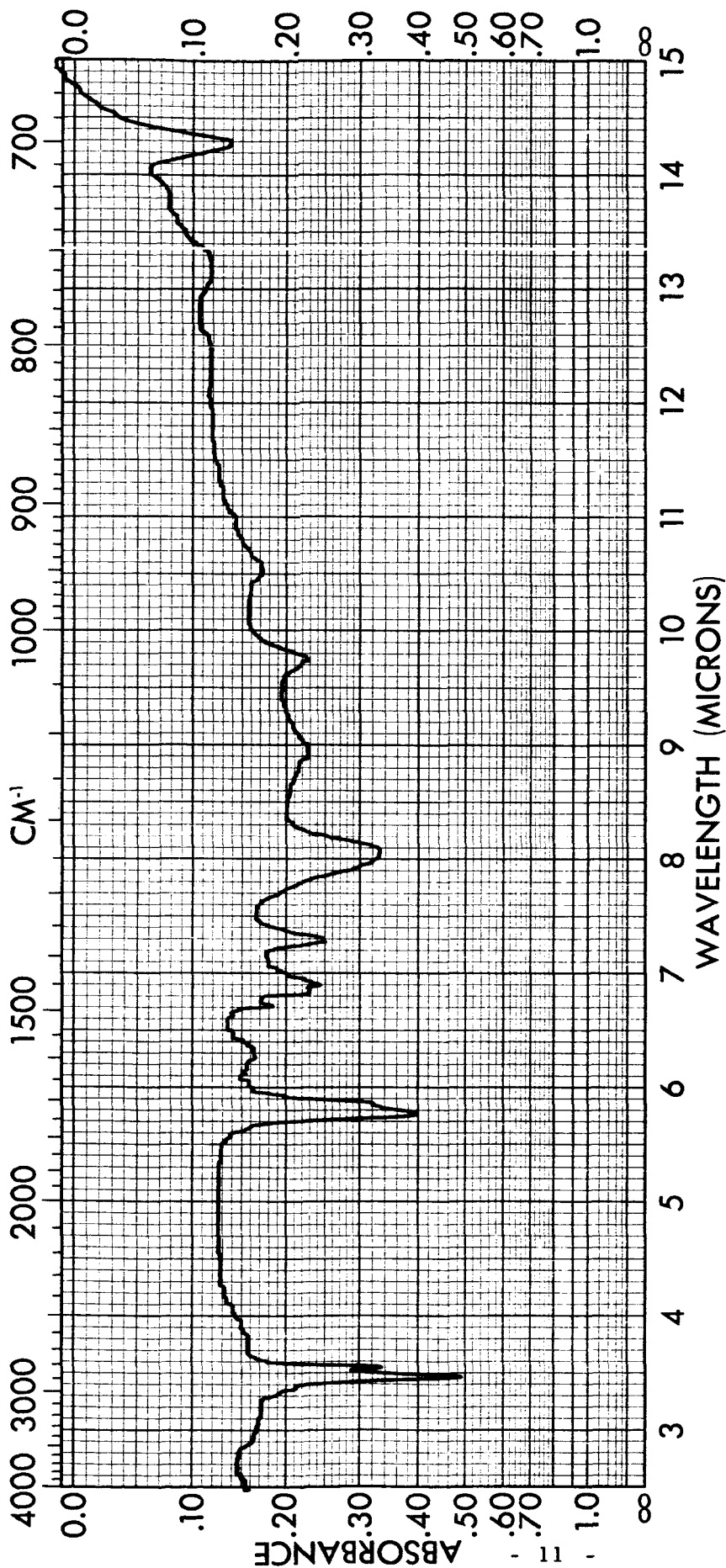
SPECTRUM NO. _____		LEGEND _____		REMARKS _____	
SAMPLE L-245-X (MIL-L-6085-A)		1. _____		_____	
PURITY _____		2. _____		_____	
PHASE _____		DATE _____		_____	
THICKNESS _____		OPERATOR _____		_____	
REFERENCE SPECIMEN					

Figure 7



SPECTRUM NO. _____		LEGEND _____		REMARKS _____	
SAMPLE <u>1601-601 &amp; 1601-601</u>		1. _____		_____	
_____		2. _____		_____	
_____		DATE _____		_____	
_____		OPERATOR _____		_____	
ORIGIN _____		THICKNESS _____		_____	
PURITY _____		_____		_____	
PHASE _____		_____		_____	

Figure 8



SPECTRUM NO. _____		ORIGIN _____		LEGEND _____		REMARKS _____	
SAMPLE 6/G-3		PURITY _____		1. _____		_____	
_____		PHASE _____		2. _____		_____	
_____		THICKNESS _____		DATE _____		_____	
_____		_____		OPERATOR _____		_____	

FIGURE 9

## CONSULTANT - LUBRICANT MANUFACTURER DISCUSSIONS

The precontract, preliminary and concluding discussions with the consultant, Lehigh Chemical Company, Chestertown, Maryland, concerning the lubricant and its environment covered a wide range of subjects. These will be roughly grouped into one, the lubricant character and description and two, the environment, including the thermal, chemical and mechanical conditions to which the lubricant is exposed in the recorder and three, the interpretation of findings. In the preliminary stages of the discussion it was possible for the consultant to make general recommendations based on background knowledge. These recommendations will generally be included with the final recommendations to minimize repetition.

### Lubricant Characteristics

All the bearings are lubricated with a diester oil meeting Mil-L-6085A specifications except those of one sub-unit (No. 600) which was lubricated with a grease meeting Mil-G-3278A specifications. The Mil-L-6085A oil is the only lubricant involved with any of the failed bearings included in the recorder. The Mil-L-6085 specification dates back to the second World War and among other requirements is one to prevent corrosion of AISI 52100 steel which was then in use for instrument bearings. The specification also was intended to prevent galvanic corrosion between the then used brass ball separator and the AISI 52100 steel. The corrosion requirements resulted in the oil manufacturer needing to use additive inhibitors. The ability of the oil to flow at -65° F and perform at maximum climatic ambient temperatures plus electric motor temperature rise are also requirements of the specification. The current practice, at the time of the specification origin, was to operate instruments for generally shorter periods between overhauls than is currently the practice. The bearings presently in operation in instruments are essentially all AISI 440-C stainless steel with stainless steel ball separators which do not require the corrosion inhibitors now in the Mil-L-6085A oils. This fact, in itself, is of no concern except that the inhibitors cause loss of performance and are not necessary to the type of bearing being employed. Specifically, the problem inhibitors are metallic sulphonates and cause difficulty by absorbing moisture into the diester oil and generally acting to cause a loss of oxidation resistance. Further, the metallic sulphonates, particularly barium sulphonate which is believed to be used in the failed oil in the subject recorder, have been involved with precipitation problems for the life of the specification. The problem may be involved in the acid balance of the oil or moisture content but the exact reason is not understood. The precipitation occurs after a period and usually shows up as a rough-looking white to tan film on the bottom of the container. The period of time required to precipitate

is difficult to determine but thought to relate to the stability of the sulphonate, the moisture content of the oil and the general housekeeping and control exercised in manufacture of the oil. The poorer the conditions apparently the sooner the precipitation occurs. Oil manufacturers' experience generally indicate that if the precipitation does not occur in six months time, it will probably not precipitate and remain stable. Under magnification the precipitate was shown, generally, to be inorganic crystalline material with a very high melting point. In short, the Mil-L-6085A specification oil does have limitations of oxidation resistance and possible precipitation problems not common to the base oil. The service life of equipment usually involved with Mil-L-6085A oil tends to be shorter than the desired life of the recorder combined with generally less power available in the recorder. The operating temperature range of the Mil-L-6085A oil is much greater than that required by the recorder, a fact which suggests a larger selection of possible lubricants than indicated by the Mil-L-6085A specification.

It is believed that it may be possible for lubricant manufacturers to meet the corrosion resistance requirements of the Mil-L-6085A specification on small batches of oil without having to use metallic sulphonates. The advances in technology make the elimination of the sulphonate possible for most manufacturers.

#### Lubricant Environment

The gas exposed to the bearings in the recorder was thought to be and later confirmed to be, normal air with some excess nitrogen due to the purging. The recorder chamber purge was confined to relatively mild pressure increases above atmospheric pressure without vacuum cycles. As a result the atmosphere inside the recorder was very near normal air oxygen and moisture content.

The materials used in the recorder which might come in contact with the lubricant were studied both for chemical and mechanical potential. Wear debris from moving components, such as belts, gears, magnetic tape and tape roll facing materials, were reviewed. Additional conversion coatings, such as chromates applied to the magnesium alloys, were all found to be potential mechanical contaminants to the bearings but thought to afford no real chemical threat, with the possible exception of the chromate conversion coatings. Subsequently, insoluble debris was found in the bearings and believed to fall into the category of mechanical rather than chemical contaminants although no specific identification was made due in part to the minute samples.

The chemical contamination potential of the various adhesives and plastics was established as acute if any were not properly cured prior to assembly of the recorder. A review of the procedures was undertaken and these were believed to be sound. It has been established that adhesives like Eastman 910, which is used in the recorder, can migrate in a vapor form and not be catalyzed and cured until condensing on a remote surface. A complete list of all materials was provided the chemical analyst as an aid to identification of the residue extracted from the bearing and a further check on the adequacy of the plastic and adhesive cure cycles.

The chemical potential of residues remaining on the completed bearings after all washing and cleaning procedures were considered and reviewed. The many grinding, lapping, washing and cleaning treatments have a potential of forming compounds between reactive additives or components and the clean base metal. Grinding coolants, for example, contain reactive additives, such as chlorine, sulphur, etc., which function by combining with the metal to form compounds adhering to the metal surfaces. To obtain background information a quantity of bearings were supplied to the analyst in a clean condition prior to the introduction of lubricant for further evaluation. It was established that no gross chemical potential existed but the tests are not considered exhaustive enough by the consultants to eliminate all possible reactions.

The lubricant is introduced into the bearings in ample quantity to wet the surface easily. The bearings are then subjected to a centrifuge treatment to remove all but a very thin film of oil. The surface area of the oil with respect to the oil volume is therefore very large. The bearings are reasonably loaded and examination established that the failures were not caused by excessive mechanical loading, nonetheless, Hertz loading in excess of 150,000 psi probably occurs routinely. In review, many elements are present which can support or aid chemical activity. The ball mill action of the bearings and its resultant pressure causing high instantaneous temperatures, the large surface area of lubricant exposed to moisture and oxygen, and the possible contributing residue films on the bearings, either acid or alkaline, together with possible influences of materials, contaminants, coatings, fingerprints and airborne dust or dirt, all combine to make any number of chemical and/or mechanical reactions conceivable.

#### Interpretation of Findings

The evidence of oxidation, shown in the infra-red spectrographic examination of both failed and non-failed recorder bearing lubricant extracts combined with the gas chromatography, led the consultant toward the

answer of lubricant oxidation. The indications of hydrolysis indicate the presence of moisture in sufficient quantity to conceivably contribute to the oxidation by reducing the oxidation resistance of the lubricant used. The lack of findings, other than oxidation, are indicative of the lack of other problems but the scope of the project in some areas do not convince the consultants that other problems are not present in addition to or supporting the oxidation which did occur. One of these areas involves the interpretation of the gas chromatography results which need further experimental work, in addition to the scope of the contract, in order to make additional identifications. Another area of doubt in the consultants' minds involves the bearing surface chemical input and the actual chemistry and age of any given lubricant and bearing. As indicated previously, the bearing surface chemistry can contribute in a number of ways including the effect of oxidizing the lubricant. In turn, the length of storage, particularly the conditions of storage, of the lubricant can contribute to reduced oxidation resistance.

## CONCLUSIONS AND RECOMMENDATIONS

The scope of the work and the magnitude of the problem do not combine to yield a complete, positive conclusion. Some areas of difficulty have been established but the recommendations do extend into suspect areas on a basis of previous good practice. The only positive conclusion reflects oxidation in the oil, therefore, the first recommendations concern themselves with reducing the oxidation problem.

### Atmosphere

Regardless of the lubricants selected, a dry inert atmosphere is highly desirable. Moisture contents of less than 1000 parts per million should be attained and a level of 500 parts per million is desirable, particularly considering the Mil-L-6085A oil actually used. If possible, an inert gas should be used and the purge of the recorder chamber accomplished on a multivacuum backfill cycle to assure displacement of the normal moist air.

### Lubricant

The adverse aspects of the Mil-L-6085A oil now used in the recorder

include the inclusion of a metallic sulphonate as a corrosion inhibitor which acts as a moisture absorber and, thereby, suppresses the oxidation resistance. It is believed that the Mil-L-6085A specification might be met by a number of manufacturers using current technology without the use of a metallic sulphonate to accomplish the required corrosion resistance. In addition to the elimination of the sulphonate, test requirements should be added to the purchasing specifications in addition to those contained in the Mil-L-6085A oil specification if it is to be continued in use. These include an ASTM precipitation test showing zero precipitation, a moisture test having 300 parts per million as a maximum, and finally a particle contamination test. The quantity of oil used in each bearing should also be increased. If the modifications of the Mil-L-6085A specification cannot be accomplished it may be necessary to change to another specification for the lubricant. This change could improve the lubrication situation considerably depending upon factors such as allowable bearing torque. In general, longer life, higher load capacity, etc., are associated with increasing the lubricant viscosity. This extends to recommendations to use a grease which is certainly in order if operating power is available to overcome the increased bearing torque. Obviously, a careful review of available power in the recorder should be made before a definite recommendation for another lubricant is made.

### Processing

The exclusion of foreign matter from the recorder assembly is of utmost importance. This requires assemblies to be built and worked on only in as dust free an environment as possible. The elimination of fingerprints and their associated chemicals, moisture, etc., from critical components is important. Although no direct finding has been made in this study with respect to dirt and fingerprints, the facts indicate that previous known failures of bearings in recorders are always the most handled bearings.

The processing refinements should be extended to result in tighter limits of control over the surface chemistry of the bearings with respect to films or residuals as well as chemical control over the oil in addition to military specification requirements.

The elimination of the present chromate conversion coating on magnesium parts is considered to be very advisable.

## Storage

Storage time and conditions have a potential adverse effect upon the performance of the oil. The extent of the effects vary and can be minimized by the conditions of storage. The reduction of unnecessary storage time, exposure to temperature, moisture, sunlight and the recommendation of this report can contribute to increased life. The documentation of storage time for any given recorder might be expanded to include date of oil manufacture and bearing manufacture as well as recorder manufacture and conditions of storage for components and final assembly.

## APPENDIX

The original failure of the NF-1 recorder was determined to involve the bearings on two shafts by investigation of Goddard Space Flight Center personnel. The four bearings concerned with the two shafts involved in the failure were forwarded to New Hampshire Ball Bearings, Inc. prior to the contract for failure analysis. The following pages contain a reproduction of that original failure analysis report.

The original report refers to Unit 609, the pressure roller, by the technician's slang term of "rubber" roller. The photographs in the original report have largely been reproduced on pages 4 and 5 and are, therefore, omitted from the appendix.

Although the order of the photographs is about the same in both the original report and the contract report, the following list is intended to aid identification of the photographs.

<u>Contract Report Section</u>	<u>Appendix Section (Original)</u>
Figure 1, Jack Shaft Bearing No.1	LWR No.61G, Spec.No.1, Figure 1
Figure 2, Jack Shaft Bearing No.2	LWR No.61G, Spec.No.2, Figure 1
Figure 3, Pressure Roller Bearing No.1	LWR No.61G, Spec.No.3, Figure 1
Figure 4, Pressure Roller Bearing No.2	LWR No.61G, Spec.No.4, Figure 1
Figure 5, Pressure Roller Bearing No.1	LWR No.61G, Spec.No.3, Figure 2
Figure 6, Pressure Roller Bearing No.1	LWR No.61G, Spec.No.3 - Not used in the original report.



AUTOPSY RESULTS OF A DUPLEX PAIR OF SR166P  
AND A DUPLEX PAIR OF SR2-5P BEARINGS  
RETURNED BY GODDARD SPACE FLIGHT CENTER

Prepared by: Engineering Department, NHBB

June, 1964

## INTRODUCTION

A pair of SR166P duplex bearings used on a jack shaft, and a duplex pair of SR2-5P bearings used on a rubber roller were removed from a unit and submitted for autopsy by Goddard Space Flight Center of NASA. The lubricant used in all four bearings was a Mil-L-6085A oil, and the unit in question was originally built, by Raymond Engineering Laboratory, Inc., for NASA.

The approximate cycling and life reported prior to failure is as follows:

26 days (624 hours) thermal cycling (0° to 50° C) in a vacuum.

25 days (600 hours) assembly and pre-environmental tests.

68 days (1632 hours) spacecraft testing part of the time under temperature cycling.

Thus an estimate of 2856 hours life.

## INSPECTION PROCEDURE

The bearings were examined, as received, for any gross damage that may have taken place that would limit operation. They were then run on the MIL-STD-206 Running Torque Tester, the Starting Torque Tester, weighted and inspected for lubricant contamination

and appearance. The bearings were then washed, and the series of torque tests and weighing repeated to determine the effect of the contamination and to measure the weight of contamination and lubricant.

Each bearing was then disassembled and inspected to determine the condition of the working surfaces and any residue remaining after washing. The SR166P duplex pair from the jack shaft are numbered Specimen 1 and 2 with the SR2-5P pair from the rubber roller number Specimen 3 and 4.

## RESULTS

The lubricant (MIL-L-6085A) is not visible as a fluid at all in one bearing (SR166P, Spec. No. 2) and appears only as a brown lubricant residue. The lubricant in the other three bearings has the appearance of being quite like heavy molasses with respect to viscosity and color, and is present in a very small quantity. White fibers are also reported as contaminants in the oil, but the volume of fibers is slight. The change in weight of the bearings before and after wash, which indicates the weight of oil plus contamination, varies from 1/2 mg to 2 mg. The experience of our Inspection Department indicates that  $1 \text{ mg} \pm 1/2 \text{ mg}$  is the weight of MIL-L-6085A oil introduced by dipping SR2-5 bearings and centrifuging at 200G for two minutes. The indication is that some of the volatile elements of the oil have been driven off, but wear debris

and foreign contamination in small amounts have compensated for the weight of oil lost.

The tabulations of running and starting torque that follow indicate a substantial improvement occurred by washing and that despite the inability of washing to remove all the lubricant residue, the resulting torque levels indicate the bearings to be in reasonably good condition. The visual inspection of the disassembled components confirms the suggestions of low torque after wash:

Running Torque (MIL-STD-206)  
in mgmm

<u>Specimen No.</u>	<u>Average Running Torque</u>			
	<u>Before Wash</u>		<u>After Wash</u>	
	<u>Ears Up</u>	<u>Ears Down</u>	<u>Ears Up</u>	<u>Ears Down</u>
1	23,000	27,000	3,000	2,200
2	50,000	42,000	3,000	3,200
3	20,000	9,500	400	200
4	13,000	7,500	300	400

<u>Specimen No.</u>	<u>Maximum Running Torque</u>			
	<u>Before Wash</u>		<u>After Wash</u>	
	<u>Ears Up</u>	<u>Ears Down</u>	<u>Ears Up</u>	<u>Ears Down</u>
1	40,000	45,000	6,400	4,800
2	86,000	84,000	6,600	8,200
3	24,000	13,500	1,100	7,400
4	24,000	21,500	1,500	1,300

Starting Torque in mgmm

<u>Specimen No.</u>	<u>Before Wash</u>		<u>After Wash</u>	
	<u>Ears Up</u>	<u>Ears Down</u>	<u>Ears Up</u>	<u>Ears Down</u>
1	H. U.	H. U.	855	944
2	H. U.	H. U.	H. U.	1,103
3	H. U.	H. U.	846	908
4	H. U.	H. U.	1,190	1,030

H. U. indicates a hangup where the torque exceeds the capability of the tester.

CONCLUSION

Considering the evidence of light wear and lubricant deterioration, it appears that a change of lubricant is needed or an improvement in the environment to which the lubricant is exposed.

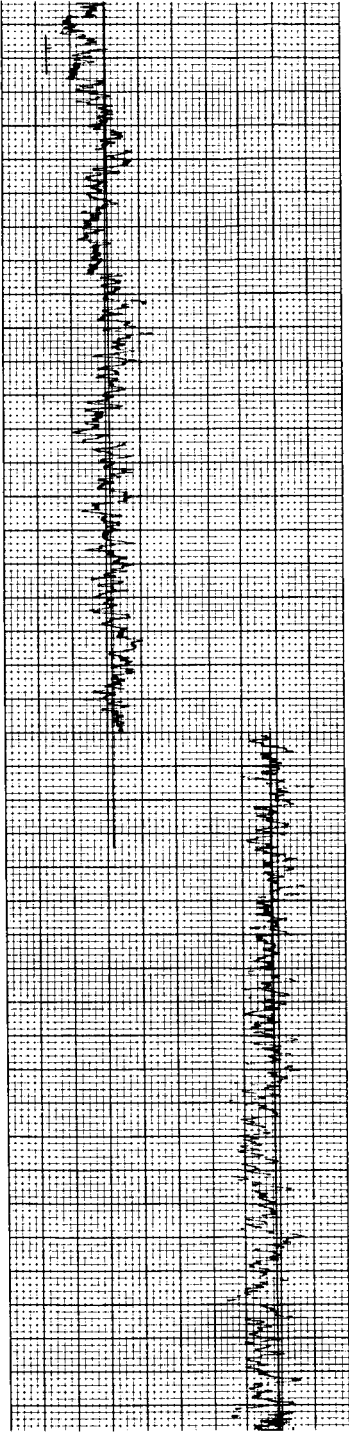
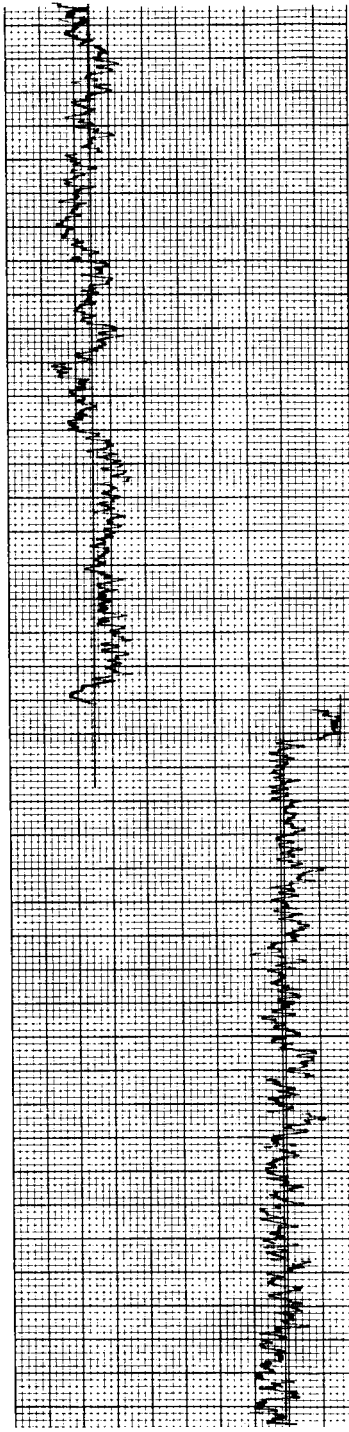
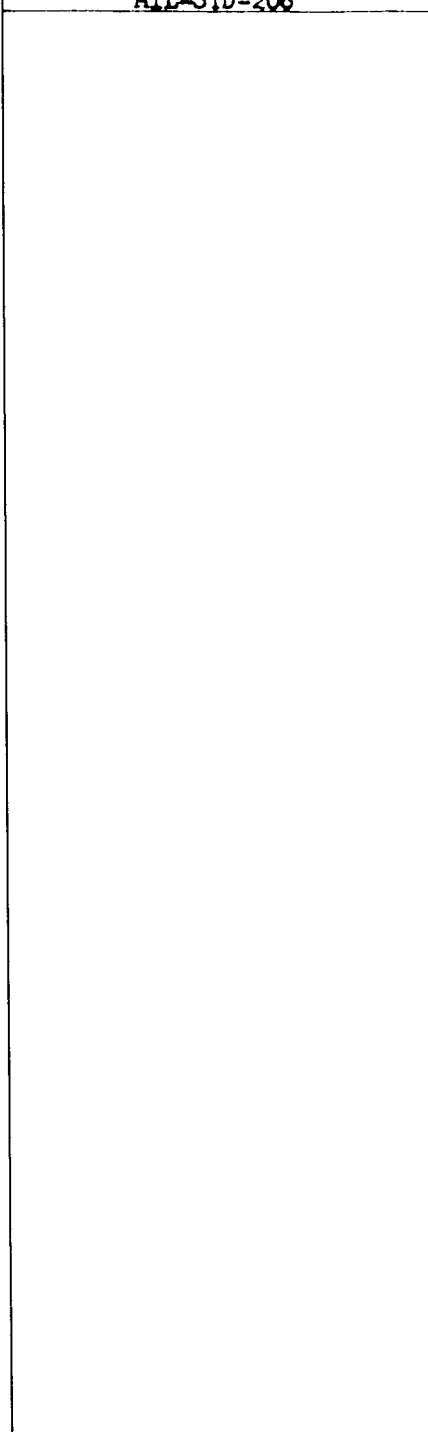
**PETERBOROUGH, N. H.**

SPEC. NO. 1  
TECH. IAS

Shield and wire - satisfactory

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT Pg.

LWR 61G SPEC. 1 DATE 6/19/64 TECH IAS

MIL-STD-206		MIL-STD-206		MIL-STD-206	
As Received Ears Up		As Received Ears Down		Ears up	
					
ATTENUATION SET. X10		ATTENUATION SET. X10		ATTENUATION SET.	
LOAD 400	gram	LOAD 400	gram	LOAD	gram
ART 23,000	mgm	ART 27,000	mgm	ART	mgm
MRT 40,000	mgm	MRT 45,000	mgm	MRT	mgm
SCALE 2000		SCALE 2000		SCALE	
mgm/div.		mgm/div		mgm/div	
HASH WIDTH		HASH WIDTH		HASH WID.	
mgm		mgm		mgm	

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT										Pg.		
LWR 61G SPEC. 1		DATE 6/19/64		TECH IAS		Dwell		Count				
MIL-STD-206					MIL-STD-206					Ears up		
After Wash Ears Up					After Wash Ears Down							
										MIL-STD-206		
ATTENUATION SET. X2			ATTENUATION SET. X2			ATTENUATION SET.						
LOAD	400	gram	400	LOAD	400	gram	400	LOAD		gram	SCALE	
ART	3000	mgm	SCALE	ART	2200	mgm	SCALE	ART		mgm	SCALE	
MRT	6400	mgm	mgm/div.	MRT	4800	mgm	mgm/div.	MRT		mgm	mgm/div.	
HASH WIDTH			HASH WIDTH			HASH WID.						

**NEW HAMPSHIRE**  **BALL BEARINGS, INC.**  
PETERBOROUGH, N. H.

ENGINEERING DEPARTMENT  
AUTOPSY REPORT FORM - Pg. 1

LWR NO. 61G      SPEC. NO. 2  
DATE 6/16/64      TECH. IAS

BRG. SIZE SR166P - Duplex Bearing      SALESMAN  
CUSTOMER NASA      APPLICATION Jack Shaft  
SPEED      BRG. TEMP.      ENVIRONMENT  
RADIAL LD.      THRUST LD      LUBE MIL-L-6085A      AMT. Unknown  
CRITERION FOR FAILURE      LIFE 2856 - total hrs  
GENERAL REMARKS Bearings installed by Raymond Engineering Lab. and removed by GSFC.  
VISUAL INSPECTION RESULTS:      RADIAL PLAY (K )  
LUBRICANT None      AMOUNT      CONDITION  
CONTAMINATION Dry grainy brown lube residue - white fibers  
REMARKS Lube residue adhered to ball path in outer ring.

INNER: GEN'L Fair to poor      FITTING MARKS, BORE Axial      RET. WEAR Moderate amber blue  
BRINELLING None      LOCATION      SHIELD INTERFERENCE None  
BALL PATH; LOCATION Off center      APPEARANCE Mod. adhesive wear  
FLAKING No      DIRT INDENTS Light      SCRATCHES Light  
OUTER: GEN'L Poor      FITTING MARKS, OD Axial      RET. WEAR None  
BRINELLING None      LOCATION      SHIELD GROOVES Clear  
BALL PATH; LOCATION Slight misalignment      APPEARANCE Med. wear-brown-amber  
FLAKING None      DIRT INDENTS Light      SCRATCHES Light polish

BALLS: GEN'L Poor      BRINELLING None      FLAKING None  
FINISH Moderate wear      DIRT INDENTS None      SCRATCHES None

All glazed brownish - blue balls

RETAINER: GEN'L Good to Fair      MATERIAL 410 Crown  
SPRING Yes      EAR SHAPE Good      DEFORMATION None  
BALL POCKET WEAR; TABS Light      BOTTOM Light  
SIDES Moderate      LOCATING SURFACE WEAR ID Hit & miss -blue -amber  
SYMMETRICAL Yes      LOCALIZED No      FRACTURED No  
FINISH Dull shine      EDGES Fairly Smooth      PUSHED OUT No      IN No

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT										Pg.	
LWR 61G -SPEC. 2		DATE 6/19/64		TECH IAS				Dwell	Count		
MIL-STD-206					MIL-STD-206						
As Received Ears Up					As Received Ears Down					Ears up	
										Ears down	
										MIL-STD-206	
ATTENUATION SET. X20			ATTENUATION SET. X20			ATTENUATION SET.					
LOAD 400	gram	4000	LOAD 400	gram	4000	LOAD	gram	SCALE			
ART 50,000	mgm	SCALE	ART 42,000	mgm	SCALE	ART	mgm				
MRT 86,000	mgm	mgm/div.	MRT 84,000	mgm	mgm/div.	MRT	mgm	mgm/div.			
HASH WIDTH			HASH WIDTH			HASH WID.					

LWR 61G SPEC. 2 DATE 6/19/64 TECH IAS

MIL-STD-206

MIL-STD-206

After Wash  
Ears UpAfter Wash  
Ears DownSmooth  
hrtr.

Dwell

Count

Ears up

Ears down

MIL-STD-206

ATTENUATION SET. X2

LOAD 400 gram 400  
 ART 3000 mgm SCALE  
 MRT 6600 mgm mgm/div  
 HASH WIDTH mgm

ATTENUATION SET. X2

LOAD 400 gram 400  
 ART 3200 mgm SCALE  
 MRT 8200 mgm mgm/div  
 HASH WIDTH mgm

ATTENUATION SET.

LOAD gram  
 ART mgm SCALE  
 MRT mgm mgm/div  
 HASH WID. mgm

**NEW HAMPSHIRE** } **BALL BEARINGS, INC**  
PETERBOROUGH, N. H.

ENGINEERING DEPARTMENT  
AUTOPSY REPORT FORM - Pg. 1

LWR NO. 61G      SPEC. NO. 3  
DATE 6/16/64      TECH. IAS

BRG. SIZE    SR2-5P - Duplex Bearing    SALESMAN  
CUSTOMER    NASA    APPLICATION    Rubber Roller  
SPEED    BRG. TEMP.    ENVIRONMENT  
RADIAL LD.    THRUST LD.    LUBE MIL-L-6085A    AMT.    Unknown  
CRITERION FOR FAILURE    LIFE 2856-Total hrs.  
GENERAL REMARKS    Bearing installed by Raymond Engineering Lab. and removed by GSFC.

VISUAL INSPECTION RESULTS:    RADIAL PLAY (K      )  
LUBRICANT    Yes    AMOUNT    Small amount    CONDITION    Thick brown-like molasses.  
CONTAMINATION    White fibers. Shiny brown gummy residue in spots on retainer and  
REMARKS    of both rings. Not removed by washing.

INNER:    GEN'L Fair to poor FITTING MARKS, BORE    Axial    RET. WEAR    Very faint  
BRINELLING    None    LOCATION    SHIELD INTERFERENCE    None  
BALL PATH; LOCATION    Off center    APPEARANCE    Lt. to mod. wear  
FLAKING    No    DIRT INDENTS    None    SCRATCHES    Lt. Polish  
Both lands amber-blue in color. Multicolored heat etch-like stains on half of ball path.  
OUTER:    GEN'L Fair to poor FITTING MARKS, OD    Axial    RET. WEAR    None  
BRINELLING    None    LOCATION    SHIELD GROOVES    Clear  
BALL PATH; LOCATION    Off center    APPEARANCE    Lt. wear - blue - amber  
FLAKING    None    DIRT INDENTS    None    SCRATCHES    Light polish

BALLS:    GEN'L    Good    BRINELLING    None    FLAKING    None  
FINISH    No visible wear    DIRT INDENTS    None    SCRATCHES    None  
All shiny balls.

RETAINER:    GEN'L    Good to fair    MATERIAL    410 Crown  
SPRING    Yes    EAR SHAPE    Good    DEFORMATION    None  
BALL POCKET WEAR; TABS    None visible    BOTTOM    None visible  
SIDES    Lightly visible    LOCATING SURFACE WEAR    ID light-amber-blue  
SYMMETRICAL    Yes    LOCALIZED    No    FRACTURED    No  
FINISH    Shiny-gummy spotted EDGES    Fairly    PUSHED OUT    No    IN    No  
smooth

LWR 61G SPEC. 3 DATE 6/19/64 TECH IAS

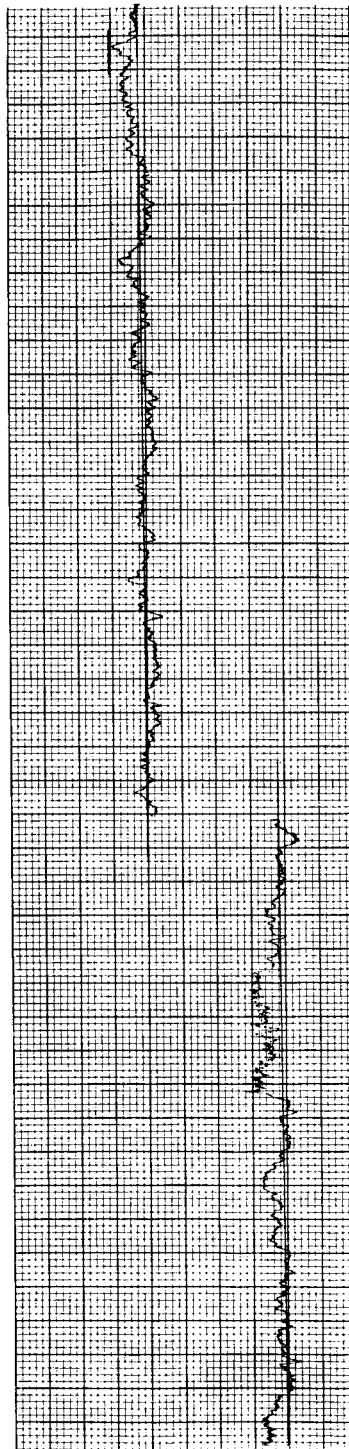
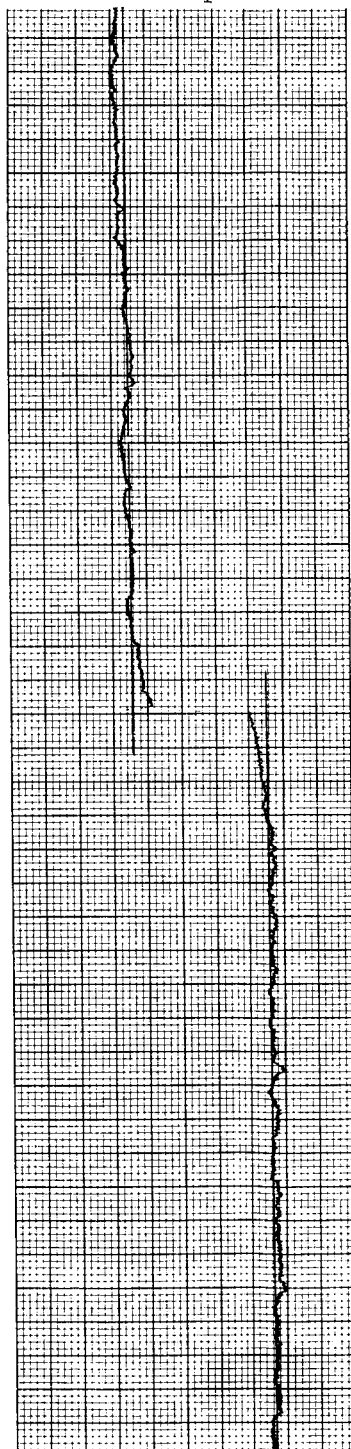
Dwell Count

MIL-STD-206

MIL-STD-206

As Received  
Ears Up

As Received  
Ears Down



Ears up  
Ears down

MIL-STD-206

ATTENUATION SET. X10

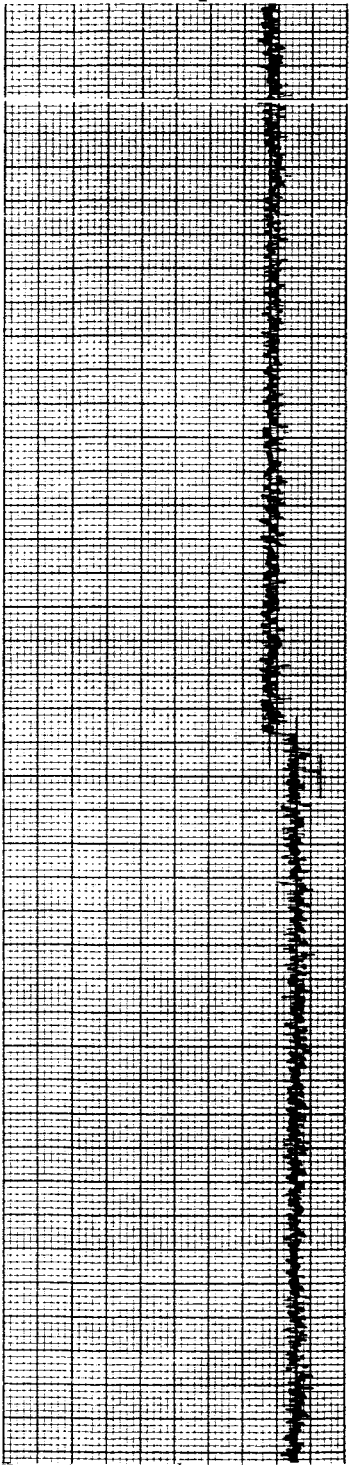
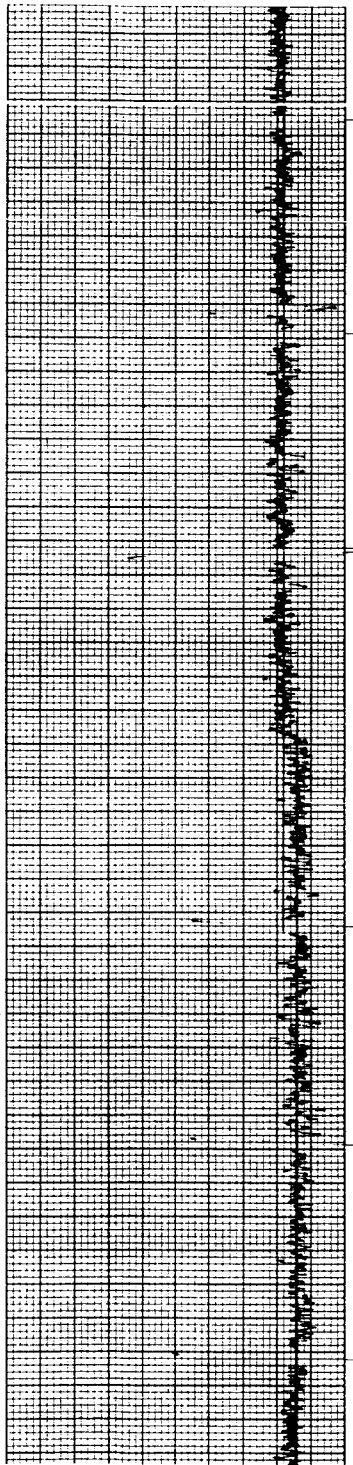
ATTENUATION SET. X5

ATTENUATION SET.

LOAD 75 gram  
ART 20,000 mgmm SCALE  
MRT 24,000 mgmm/mgmm/div  
HASH WIDTH mgmm

LOAD 75 gram  
ART 9,500 mgmm SCALE  
MRT 13,500 mgmm/mgmm/div  
HASH WIDTH mgmm

LOAD 75 gram  
ART 9,500 mgmm SCALE  
MRT 13,500 mgmm/mgmm/div  
HASH WID. mgmm

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT										Pg.				
LWR		61G		SPEC.		3		DATE		6/19/64	TECH	IAS		
MIL-STD-206						MIL-STD-206						Smooth Ears up Ears down	Dwell	Count
After Wash Ears Up						After Wash Ears Down								
													MIL-STD-206	
ATTENUATION SET. X1						ATTENUATION SET. X1						ATTENUATION SET.		
LOAD	75	gram	200	LOAD	75	gram	200	LOAD		gram		SCALE		
ART	400	mgmm	SCALE	ART	200	mgmm	SCALE	ART		mgmm		SCALE		
MRT	1100	mgmm	mgmm/div.	MRT	7400	mgmm	mgmm/div.	MRT		mgmm		mgmm/div.		
HASH WIDTH			mgmm	HASH WIDTH			mgmm	HASH WID.				mgmm		

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PETERBOROUGH, N. H.

ENGINEERING DEPARTMENT  
AUTOPSY REPORT FORM - Pg. 1

LWR NO. 61G      SPEC. NO. 4  
DATE 6/16/64      TECH. IAS

BRG. SIZE SR2-5P - Duplex Bearing      SALESMAN  
CUSTOMER NASA      APPLICATION Rubber Roller  
SPEED      BRG. TEMP.      ENVIRONMENT  
RADIAL LD.      THRUST LD.      LUBE MIL-L-6085A      AMT. Unknown  
CRITERION FOR FAILURE      LIFE 2856-total hrs.  
GENERAL REMARKS Bearing installed by Raymond Engineering Lab. and removed by GSFC.

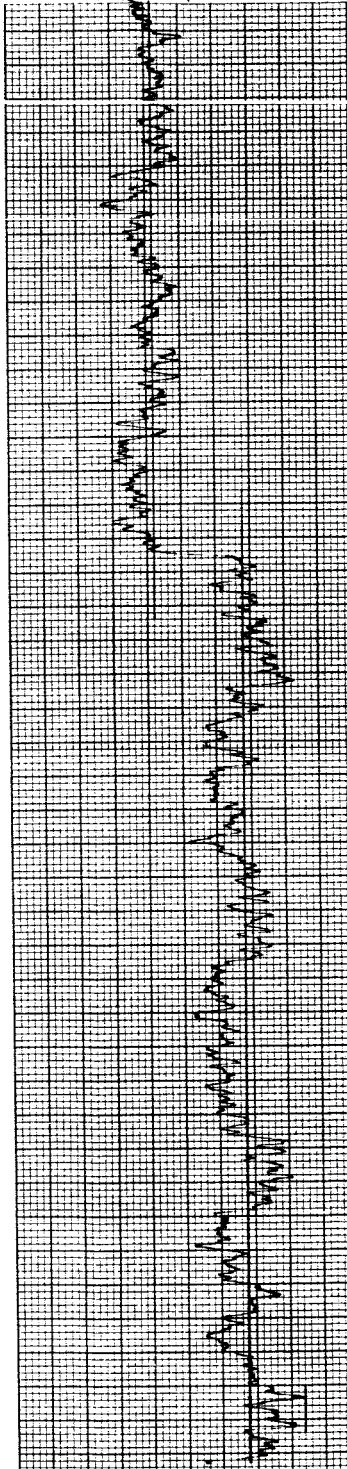
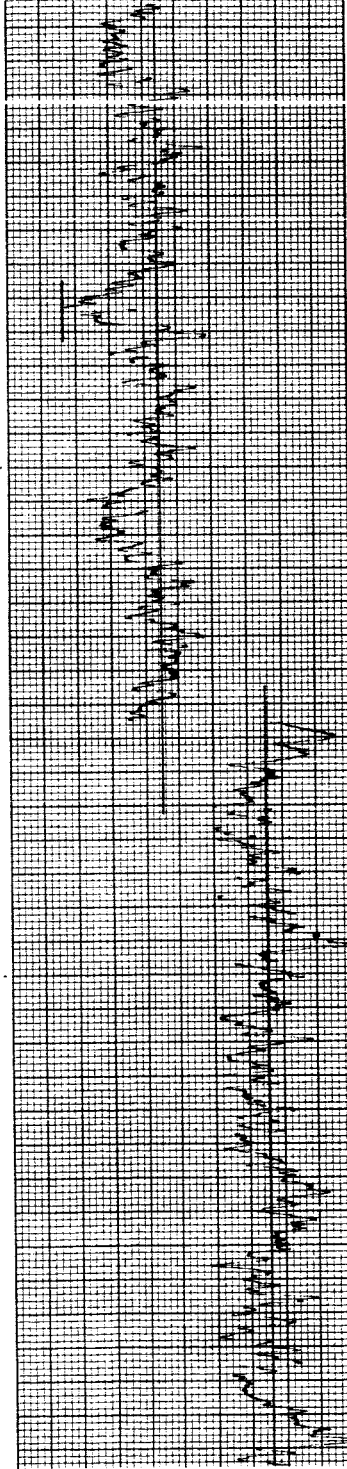
VISUAL INSPECTION RESULTS:      RADIAL PLAY (K )  
LUBRICANT Yes      AMOUNT Small amount      CONDITION Thick brown like  
molasses  
CONTAMINATION White and colored fibers. Shiny brown gummy residue in spots on  
REMARKS retainer. Not removed by washing.

INNER: GEN'L Poor      FITTING MARKS, BORE Axial & circular      RET. WEAR Light  
BRINELLING None      LOCATION      SHIELD INTERFERENCE None  
BALL PATH; LOCATION Off center      APPEARANCE Mod. adhesive wear  
FLAKING No      DIRT INDENTS Light      SCRATCHES Light polish  
Slight slippage in bore.

OUTER: GEN'L Poor      FITTING MARKS, OD Axial      RET. WEAR  
BRINELLING None      LOCATION      SHIELD GROOVES Clear  
BALL PATH; LOCATION Off center      APPEARANCE Mod. wear amber-blue  
FLAKING No      DIRT INDENTS Light      SCRATCHES Light polish

BALLS: GEN'L Poor      BRINELLING None      FLAKING None  
FINISH Lightly frosted      DIRT INDENTS Light      SCRATCHES Light  
Blue-amber equator bands on each ball.

RETAINER: GEN'L Good to fair      MATERIAL 410 Crown  
SPRING Yes      EAR SHAPE Good      DEFORMATION None  
BALL POCKET WEAR; TABS Light      BOTTOM None visible  
SIDES Light      LOCATING SURFACE WEAR ID - light  
SYMMETRICAL Yes      LOCALIZED No      FRACTURED No  
FINISH Shiny-gummy      EDGES Fairly      PUSHED OUT No      IN No  
spotted      smooth

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT										Pg.			
LWR 61G SPEC. 4		DATE 6/19/64		TECH IAS		Dwell		Count					
MIL-STD-206					MIL-STD-206					Smooth Ears up Ears down			
As Received Ears Up					As Received Ears Down								
													
										MIL-STD-206			
ATTENUATION SET. X10					ATTENUATION SET. X5					ATTENUATION SET.			
LOAD 75	gram	2000	SCALE		LOAD 75	gram	1000	SCALE		LOAD	gram	SCALE	
ART 13,000	mgm				ART 7,500	mgm				ART	mgm		
MRT 29,000	mgm	mgm/div.			MRT 21,500	mgm	mgm/div			MRT	mgm	mgm/div	
HASH WIDTH					HASH WIDTH					HASH WID.			

NEW HAMPSHIRE BALL BEARINGS, INC. ENGINEERING DEPT. LIFE TEST AUTOPSY REPORT Pg.

LWR 61G SPEC. 4 DATE 6/19/64 TECH IAS

MIL-STD-206

MIL-STD-206

After Wash  
Ears Up

After Wash  
Ears Down

	Dwell	Count
Ears up		
Ears down		

MIL-STD-206

ATTENUATION SET. X1  
LOAD 75 gram 200  
ART 300 mgmm SCALE  
MRT 1500 mgmm/mgmm/div.  
HASH WIDTH mgmm

ATTENUATION SET. X1  
LOAD 75 gram 200  
ART 400 mgmm SCALE  
MRT 1300 mgmm/mgmm/div  
HASH WIDTH mgmm

ATTENUATION SET.  
LOAD \_\_\_\_\_ gram  
ART \_\_\_\_\_ mgmm SCALE  
MRT \_\_\_\_\_ mgmm/mgmm/div  
HASH WID. \_\_\_\_\_ mgmm